PRECIPITATION AVERAGES FOR THE STATE OF WASHINGTON, AS AFFECTED BY HABITABILITY

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Fluctuations in averages for State caused by extreme stations.—The normal annual precipitation at the individual measuring stations in the State of Washington ranges from 6 inches for the driest to approximately 150 inches for the wettest. Manifestly with so wide a spread between the extremes, averages for the State as a whole may show considerable variation according to the proportions of stations in the wetter, or drier, districts. If the value of 35 inches be used as a State normal, which is a conservative figure, based upon 190 of the 202 stations now in existence, then the establishment of 1 new station in the wettest region, where the normal may be 150 inches, will mean the inclusion of a station having 115 inches a year more than the State normal and this alone would raise the State normal more than a half an inch and the addition of 2 such places, more than an inch. On the other hand, the addition of a station with but 6 inches a year would mean that its normal is only 29 inches a year less than the State normal. Hence more than 6 such stations would be required to reduce the State normal by 1 inch, or 3 times as many as would be required to raise the normal an inch.

Present trends.—The development of the Climatological Service of necessity has not proceeded along such a balanced increase in new stations. Quite the contrary. For years the increase in the number of the wetter stations has actually been considerably greater than for those in the arid and semiarid regions. Consequently State averages have continued to show increased precipitation, notwithstanding the fact that during most of this period the State was in a cycle of decreasing precipitation, which reached a minimum in the years 1929 and 1930 as shown by stations in operation throughout the period.

Greatest cause of fluctuation: Habitability.—It is the object of this paper to discuss the variations in the distribution of observing stations from decade to decade and the principal cause thereof, that of habitability, using the term in its broadest meaning. No such admirable and even distribution of measuring stations has been possible as may be found in States that have more nearly homogenous lands, practically every acre of which is arable. In the more rugged and mountainous regions the problem has been to "Find the observer." Campaigns have been carried on in times past with that in view, while for a number of years the section center has been especially alert to secure observers in the unrepresented areas. There has been a great demand for information from the mountains and foothills in connection with water resources, which must supply cities and towns, irrigate the desert and semidesert lands, and furnish the motive power for hydroelectric development. The proportion of new stations in the foothills and mountains has been large in the past 25 years. There still remain areas of 300 to 400 square miles without a station. On the other hand, in some well-settled districts the interest in meteorological data has been so great that in some sections private and public agencies have provided their own equipment, and stations on a location map appear like telegraph poles along a right-of-way, they are relatively so close together. In the upper portion of the Yakima Valley from Ellensburg, elevation 1,510 feet, to the summit of the Cascades in Snoqualmie Pass, elevation 3,010 feet, are 6 measuring stations in an air-line distance of less than 52 miles, and the range in precipitation is from slightly over 9 inches to 91 inches. Some of these stations were established by the Weather Bureau and some by the Bureau of Reclamation at three large lakes that supply irrigation water to the valley. Each of the stations is quite different from every other and all are important. It so happens that there are now four official observing stations in Seattle. The oldest is the main office in the downtown district. The University of Washington has maintained a cooperative station on the campus for many years. More recently the Weather Bureau established the Airport Station at Boeing Field in the extreme southern part of the city, while the naval air station was located a short distance beyond the city limits to the northeast. The four stretch out some 15 miles and are spaced about 5 miles apart.

Sparsely inhabited regions.—The conspicuous areas without observers have been, and still are, in the mountains, the arid regions, and in the remote forests. The mountains have been forbidding as a place of permanent dwelling because of their inaccessibility and ruggedness, because of dense timber that must be penetrated to reach them, and because of the very deep snows of the winter-half of the year. The arid regions have failed to properly support life. But habitability is relative. The railroads crossed the States from east to west and station agents became weather observers in the driest places and in mountain passes. At the summits or at the entrances to tunnels, the railroads must continually have stations in order to maintain clear tracks and to operate trains over steep grades. Irrigation has changed some barren, sagebrush, jack rabbit, and coyote valleys into the most desirable places for intensive horticultural and agricultural pursuits and has multiplied opportunities for obtaining observers far beyond any reasonable need. An occasional mine has been an observing point, but as a rule, the records may be kept faithfully for a few years and then perhaps the mine be abandoned. Some very good mining stations are now functioning. With the development of irrigation there also has been a material increase in the number of stations at reservoirs and lakes in the mountains and foothills where it has been necessary to maintain a keeper. Hydroelectric companies and municipalities have pursued a similar course, notable among which are the Puget Sound Power & Light Co. and the cities of Seattle, Tacoma, Walla Walla, Everett, Aberdeen, Hoquiam, and others. In recent years the establishment of mountain resorts has contributed to the number of the more elevated stations. The Rainier National Park, embracing 100 square miles, has three cooperating stations, and there are others in the national forest surrounding the park. Mount Baker has one. The Portland Y.M.C.A. has a permanent establishment on the shores of Spirit Lake on the northerly slopes of Mount St. Helens. When the Milwaukee Railroad built its tunnel through the Cascades it abandoned the station in Snoqualmie Pass, but later an inn was erected on the highway by private enterprise, which was operated at first only when the snow was gone. Now the State highway department maintains an open road throughout the winter despite the deep snows, and the weather records are continuous, in fact an airways observing station is now maintained there. Since skiing

has become popular, many of the winter resorts are open in winter as well as in summer, and records are likewise continuous. The State highway department plans to keep open other passes through the Cascades as funds become available. The forested areas, especially the national forests, have contributed a number of new stations. Many of these were established in connection with the fire-weather work of the Bureau. National and State forestry services and private agencies interested in logging operations have cooperated in observing precipitation and humidity.

The foregoing development has made it possible for one or more persons to dwell in the inhospitable places, and some of the valleys have become well populated by reason of irrigation, yet the rugged mountains as a whole are still unable to attract, retain, or support permanent residents. The term habitability has been used in a very relative sense.

Normal precipitation.—In practice the normal precipitation for a State is an average of the normals for a number of places as uniformly distributed over the entire area as possible. A normal precipitation weighted according to density of population would seem rather absurd, and yet to a certain extent this has actually resulted in Washington, and without doubt, in most of the other mountainous States. Insofar as such a normal represents the precipitation where the masses now live and will continue to live in large numbers, it serves a valuable purpose. At least, such an average is more useful to the majority of citizens. The seeker for reliable information should always consult the normals for individual stations. There is no substitute that will suffice. In a Seattle second-hand book store is a meteorological atlas for the United States which was published in the early nineties. Within it are portrayed many climatic charts. All of northwestern Washington is indicated to have more than 60 inches of precipitation annually. The author's chart was prepared using only two stations in that section; Neah Bay, which has an annual rainfall of more than 100 inches, and Olympia which has 52 inches. Port Townsend had a record at that time. It was formerly Fort Townsend, centrally located within that region. Its normal is less than 20 inches, while Sequim, which is also in the lee of the Olympic Mountains, has averaged less than 17 inches, and irrigation is practiced there.

Opposite trends.—In the distribution of new stations in the State, there are two somewhat opposing trends as to whether the State normal shall increase or decrease. The one is the location of stations where people may flock and the other the location of measuring stations with a view to further determining the water resources in the mountains. On the whole, the former will probably tend to reduce the normal and the latter to increase it. When the Grand Coulee Dam project is finally completed, more than a million acres of either totally unproductive or partially productive land will come under intensive cultivation, and will support a considerable horticultural and agricultural population, and will make possible observing stations in a now poorly represented dry region. Other development will make possible communities and observing points where representation is inadequate. Most of these are apt to be either dry or moderate in precipitation. The amount of precipitation a region may have is, as a rule, not the determining factor in the density of population. The most populous region of the State is the east shore of Puget Sound where the transcontinental railroads first reached tidewater, and a great and deep inland harbor was available for cheaper vessel transportation. The cities of Seattle and Tacoma are the nearest points to the passes in the Cascades used by the railroads, and in this region also was a wealth in lumber and fish. Here people naturally congregated and the results probably would not have been greatly different had Seattle's normal precipitation of 34 inches and Tacoma's 40 inches been double, as is the case on Grays and Willapa Harbors. The latter places are prosperous regions with small cities, whose principal handicap has been that railroads must travel more than 100 miles farther to reach tidewater. The demand for more data from the mountains is constant since their heavy rains and snows afford millions of potential horsepower as the water cascades to form the larger streams and moves in a mighty volume to the sea and the rains and snows nurture billions of feet of timber. No doubt the increase in stations in these wetter districts will more than offset the influence of new stations in drier sections.

Quadrangles to equalize the distribution of stations.—Since the distribution of stations was so uneven, Summers divided the State into 15 so-called quadrangles, all of approximately equal areas and the terrain and other conditions as nearly homogenous as it was possible to attain. This system was put into effect in 1927 and is now in use in computing both temperature and precipitation monthly and annual averages. It affords a fairer distribution on a somewhat more nearly geographical basis. Figuratively, Seattle gets four votes in its quadrangle average but the quadrangle represents only one-fifteenth of the State average.

TABLE 1.—*Normals of precipitation for Washington computed from present day normals for individual stations in operation at the end of successive decades. Straight averages except as indicated*

Year	Number of stations			Normals		
	West	East	State	West	East	State
1890	16	4	20	47.82	13.48	40.96
1900	33	35	68	56.42	14.10	34.64
1910	39	57	96	56.78	15.81	32.46
1920	58	82	140	55.50	16.20	32.48
1930	88	102	190	63.42	16.56	38.24
	By quadrangle method					
1930	88	102	190	59.95	22.84	35.21

Distribution of stations at the end of each decade and the corresponding averages (see table I).—State averages for the various months and years have been prepared and are now in use for each year as far back as 1890, when apparently only twenty stations were in operation. Of these, 16 were in western Washington and only 4 in the eastern part of the State or in the ratio of 4 to 1. By "western Washington" is meant all that section of the State west of the summit of the Cascade Range, and "eastern Washington" is all that to the east. The ratio of the two areas is approximately 1 to 2. Thus it will be seen that in 1890 there was a great distortion in the averages for the State due to this distribution, since the smaller division had four times as many stations as the larger. Using present-day normals for each of these 20 stations, their average makes 41 inches for the normal for the State, an amount greater than obtained from any other computations. Yet the normals for each division are less than ever subsequently obtained. The reason for the larger number of stations in western Washington at that time is that there was more activity in that part of the State. Only one of the stations west

of the Cascades was not on a body of water reached by ocean vessels, and that one, Chehalis, lies in a wide fertile valley about midway between Puget Sound and the Columbia River. None of the 16 was even in the foothills. The wettest stations were in the extreme northwest, and were at Tatoosh Island, Neah Bay, and La Push. The average for western Washington was 47.82 inches, while that for the four stations in the eastern division was 13.48 inches. The 2,000 miles of shoreline, including that part of the Columbia River touching Washington west of the Cascades, the ocean coast including Willapa and Grays harbors, the Straits of Juan De Fuca and Puget Sound with its many ramifications and islands offered ready and inviting sites for habitation. By 1900 the situation as regards distribution of stations was better, with 33 in the west and 35 in the east, or a total of 68, yet the west still had an undue proportion so far as geographical distribution was concerned. A straight average of present day normals for the 68 stations gives the State a normal of 34.68 inches or more than six inches less than the 1890 figures, and this, notwithstanding the fact that the normal for western Washington rose to 56.42 inches due to the addition of a number of very wet places including two in the mountains. The average for the east becomes 14.10 inches or nearly an inch more than the average of the four 1890 stations. The 10 years ending with 1900 has proved to be actually the wettest decade of the four decades under consideration. The reduction in the normal is due to the change in the relative proportion of stations in the east and west divisions of the State.

In 1910 the number of stations in the west had risen to 39 while in the east the number shows a greater increase to 57. The west continued, however, to have more than its proportion according to area ratio of 1 to 2. A straight average of the 96 station values makes a State normal of 32.46 inches or nearly two inches less than the 1900 normal and 8½ inches less than the 1890 normal. For the west the normal increased slightly while for the east it rose to 15.81 inches or 1.71 inches more than it was for 1900. Here we find that the average for each division taken separately shows an increase, yet that for the State shows a decrease again due to the change in the proportionate distribution. The reason for the increase in the normal for the eastern division was that in 1909 began a campaign to secure more precipitation measuring stations in the mountains and also to the fact that gages were placed at forest ranger stations.

In 1920 the total number of stations had increased to 140; 58 in the west and 82 in the east. In this case the west increased more than the east, further distorting the proportion. However, the State average rose only 0.02 inch. The normal for the west decreased to 55.50 inches or 1.28 inches less than in 1910, while in the east the average rose 0.39 inch to 16.20 inches. There was a notable increase in stations in the mountain regions of eastern Washington, especially in the Yakima drainage basin, where the great irrigation project was being further developed, while in the west there were new stations in the drier portions and also some in the wetter.

In 1930 the number of stations had risen to 202; however some 12 of these have such short records that no attempt was made to include normals for them. Of the 190 stations used, 88 were in the west and 102 in the east, the west having far too many to balance the 1:2 area ratio. There was a 50 percent increase in stations in the west and only a 25 percent increase in the east. Two-thirds of the new stations west of the Cascades summit were in the wetter mountain or forested regions, while a smaller proportion of those east were thus located. Using a straight average, as was done in the preceding computations, the State normal rises to 38.24 inches, or nearly 6 inches at the very time when individual stations over the State were showing the driest decade, which include the record breaking years of 1929 and 1930. Had the new stations been similar to the old, and if the proportion of stations had remained undisturbed the normal would have shown a decrease instead of a marked increase. For western Washington the straight average exceeds 63 inches and for the east 16.56 inches. It is quite apparent that with so large a proportion of the stations in the wettest sections of the State the average obtained is not fairly representative if equal areas are to be considered. If all the stations are distributed to their respective quadrangles and each quadrangle averaged separately and then the 15 quadrangle averages combined, the normal for the State becomes 35.21 inches; 59.95 for the west and 22.84 for the east. This allocation of stations lowers the average for the western division but increases it for the eastern. It so happens that the average thus obtained for the State, of 35.21 inches, is only a small amount greater than the period average of the yearly averages for the State.

Summers, after exhaustive computations extending averages back much farther and estimating normals for all the new stations, found that distributed by quadrangles the State normal is about 39 inches.

Precipitation on ridges and peaks not evaluated.—Another phase of habitability is that a large proportion of stations are in the valleys or the lower places, for the railroads and highways seek the easier grades and in the valleys are apt to be the most fertile fields. It has been shown that the most populous places west of the Cascades are at or near sea level and even in eastern Washington on the plateau the towns are in the coulees for the most part and many a rancher avoids the stronger winds of the ridges. Comparatively little is known of the precipitation on the ridges, hilltops, and mountain peaks. A state normal to be truly representative on a geographical basis might have to show a measuring station for every square mile, so great are the variations, and such a normal would need to include the summits of Mounts Rainier, Adams, Baker, Glacier, and Saint Helens with their eternal snows and glaciers. Such an eventuality seems rather incredible. Yet one advertising enthusiast has already sought to establish a winter residence and radio station on the summit of Mount Rainier and wishes meteorological equipment. A normal so representative as outlined seems about as remote as infinity, yet as time passes no doubt more observing points will be placed in sections now unrepresented.

Whatever value for the normal precipitation for the State a Section Center may use, it should bear a close relation to the stations that are active, otherwise a monthly State average may be greater than the normal, while the great majority, or even all of the individual stations may show a deficiency.